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A WALL INTERFERENCE ASSESSMENT/CORRECTION SYSTEM

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Title: A Wall Interference Assessment/Correction System

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Technical Objectives

A Wall Signature method originally developed by Hackett has been selected to be adapted for the Ames 12-ft Wind Tunnel WIAC system in the project. This method uses limited measurements of the static pressure at the wall, in conjunction with the solid wall boundary condition, to determine the strength and distribution of singularities representing the test article. The singularities are used in turn for estimating blockage wall interference. The lifting interference will be treated separately by representing in a horseshoe vortex system for the model's lifting effects. The development and implementation of a working prototype will be completed, delivered and documented with a software manual.

The WIAC code will be validated by conducting numerically simulated experiments rather actual wind tunnel experiments. The simulations will be used to generate both free-air and confined wind-tunnel flow fields for each of the test articles over a range of test configurations. Specifically, the pressure signature at the test section wall will be computed for the tunnel case to provide the simulated "measured" data. These data will serve as the input for the WIAC method--Wall Signature method. The performance of the WIAC method then may be evaluated by comparing the corrected data with those of the free-air simulation.

The following two additional tasks are included in the supplement No. 1 to the basic Grant. (1) On-line wall interference calculation: The developed wall signature method (modified Hackett's method) for Ames 12-ft Tunnel will be the pre-computed coefficients which facilitate the on-line calculation of wall interference. and (2) Support system effects estimation: The effects on the wall pressure measurements due to the presence of the model support systems will be evaluated.

Status of Progress

A. Wall Signature Method

The Wall Signature method is investigated to calculate the blockage correction in the NASA/ARC 12-ft Pressure Wind Tunnel. The lifting correction is determined separately and reported in the next section. In the last reported period, the blockage correction was developed and implemented for a rectangular tunnel as well as the 12-ft Pressure Tunnel(Refs 1, 2 & 3). An equivalent body geometry in terms of surface panel elements has been used in the modified form of the Wall Signature method. The blockage correction was computed by the panel code PMARC(Ref 4) directly with this form of the Wall Signature method.

In the present reported period, an equivalent body is mathematically represented by a line source and a line sink as given in Ref. 5. The PMARC panel code is required to be modified to compute the interference and wind tunnel flow field of a line source and a line sink in the NASA/ARC 12-ft Tunnel. The modified PMARC code is combined with the Wall Signature analysis to compute influence functions and blockage corrections. The basic elements of the signature method including (1) wall signature analysis and (2) interference calculation are described in details in Appendix I.

Results. An example is given herein to demonstrate the application of the Wall Signature Method to the NASA/ARC 12-ft Pressure Wind Tunnel. The flow field of a finite span rectangular wing with NACA 0012 airfoil section and trailing edge wake in the 12-ft Pressure Wind Tunnel is simulated using panel code PMARC. The geometric data and the panel arrangement are shown in Fig. A-1 and Fig. A-2, respectively.

In a first step, the panel code PMARC was utilized to determine surface pressures in the free-air and wind tunnel flow field using the test article and trailing edge wake geometry given in Fig. A-2. Figure A-3 shows the computed surface pressure distribution in the free-air and wind tunnel flow field on the selected model surface location. The wall pressure distribution is calculated and random disturbances are added to the signature to simulate a wall pressure measurement which is indicated by solid line as shown in Fig. A-4.

The wall signature method is applied to this simulated wall pressure signature and the description of the equivalent body is found. Figure A-4 shows the result of the signature analysis procedure which is described in Appendix I. Based on the known equivalent representation of the test article and wake it is now possible to compute a blockage correction. This blockage correction is depicted as the dashed line in Fig. A-5 and shows excellent agreement with the reference solution which is computed and depicted as a solid line.
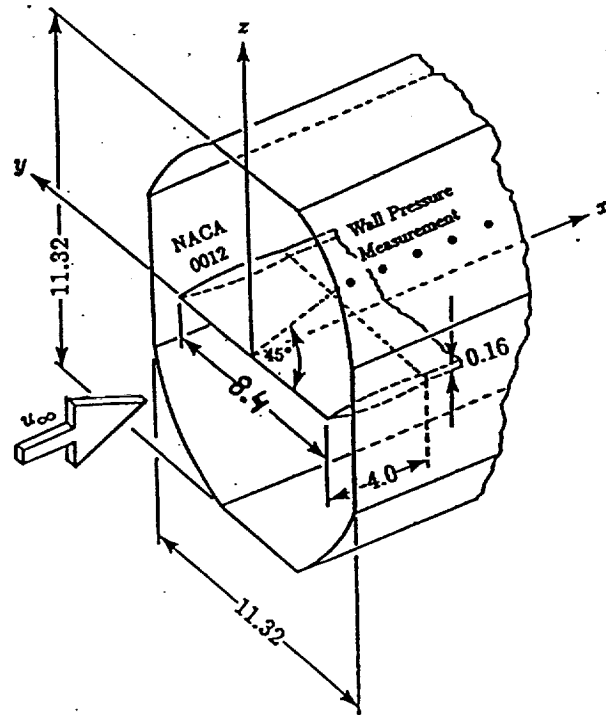
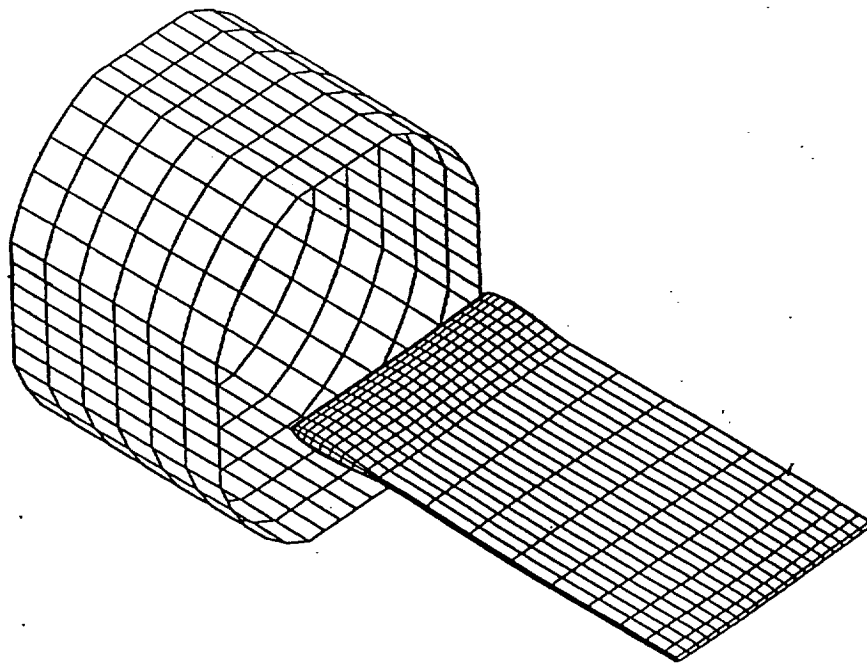**Fig. A-1.** Geometry of NASA/ARC 12ft Pressure Wind Tunnel with NASA 0012 Airfoil and Simulated Wake.

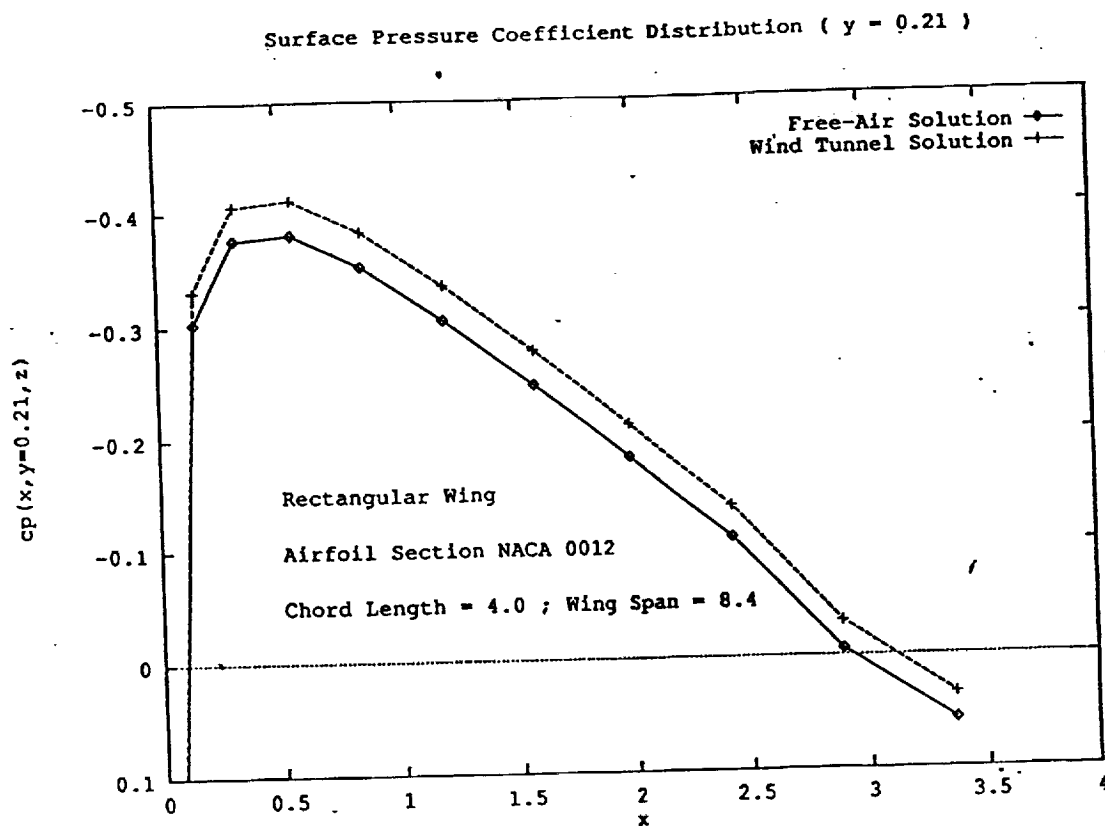**Fig. A-2.** Location of test article and wake panels in NASA/ARC 12ft Pressure Wind Tunnel.
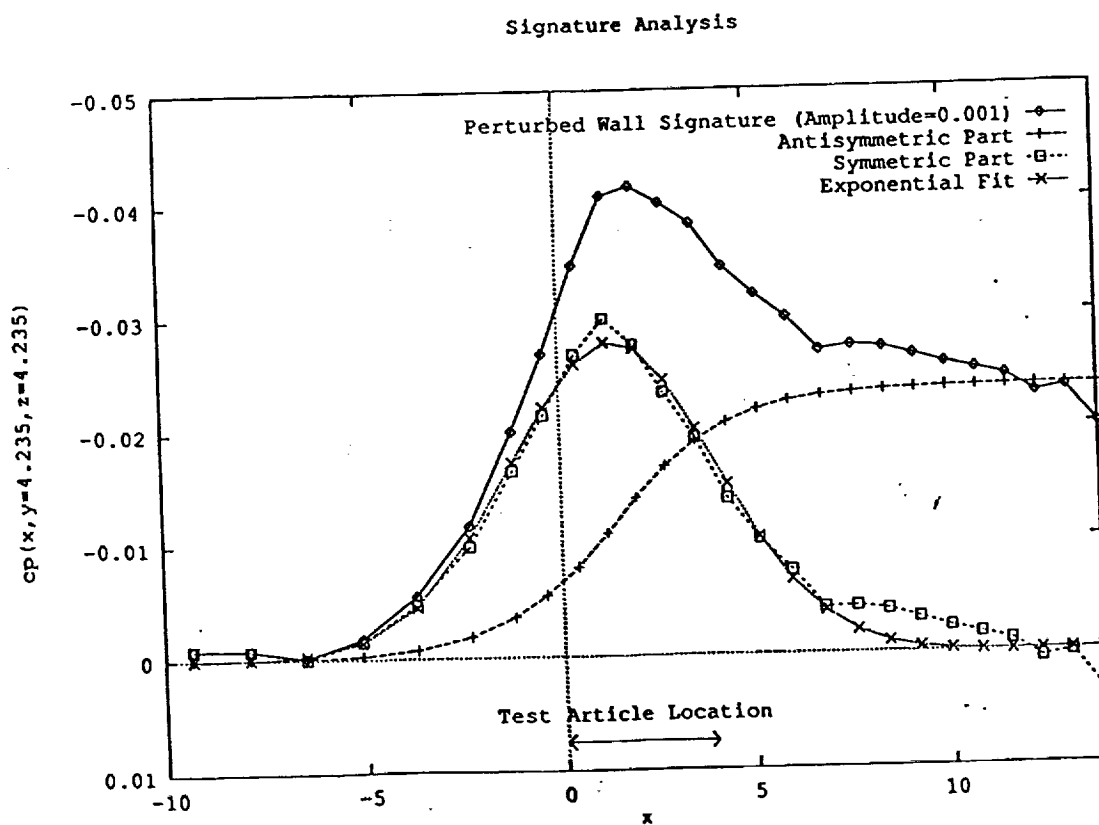
Fig. A-3. Model surface pressure distribution; y = 0.21 .

Signature Analysis

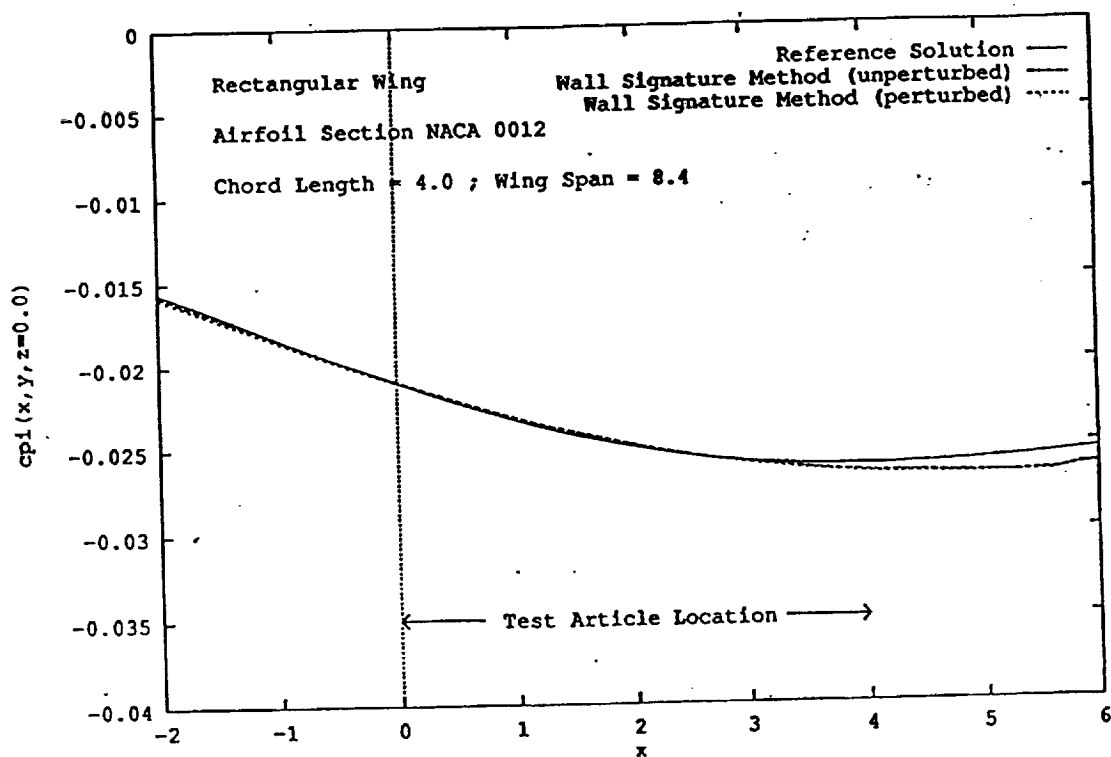Fig. A-4. Signature analysis of wall signature.

Fig. A-5. Blockage correction at $y = 0.21$.

B. Lifting Interference Prediction

The lifting interference is modeled by a horseshoe vortex system as shown in Fig. B-1 with a finite length of trailing vortex as the finite tunnel length.[*] The measured lifting force of a test article is used to determine the strength of the horseshoe vortex. The calculation of the lifting model will provide both wall interference on the model and the effects on the wall pressure signature. Then the effects on the wall signature can be removed and the net wall signature solely induced by the blockage effect can be used to compute the blockage interference correction as described in the Section A.

Verification of the lifting calculation was conducted in a rectangular tunnel with the reference solution from the image method. The lifting interference was computed by incorporating the finite span horseshoe vortex with the PMARC code as described in Appendix II. It is shown that the excellent agreement of the present results and those obtained by the image method for the effects on the wall pressure at a selected line in Fig. B-2 and the lifting interference along the tunnel centerline in Fig. B-3. These results has validated the calculation of the PMARC with a lifting horseshoe vortex system if disregarding the end effect of the finite tunnel length.

Results. The results of the lifting effects in the Ames 12-ft tunnel are calculated by the modified PMARC. The wall pressure effects along the 45 degree line are shown in Fig. B-4. The lifting interference at the tunnel centerline as given in Fig. B-5 is at the same level of a square tunnel. As discussed before, the pressure effects due to the lifting effects will be removed from the wall pressure signature for the blockage correction study.

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[*]It should be noted that the infinite length of trailing vortex with the finite length of tunnel gives the similar results. However, it reduces the number of iterations in running PMARC code. Thus the finite length of trailing vortex is chosen for the present calculation.
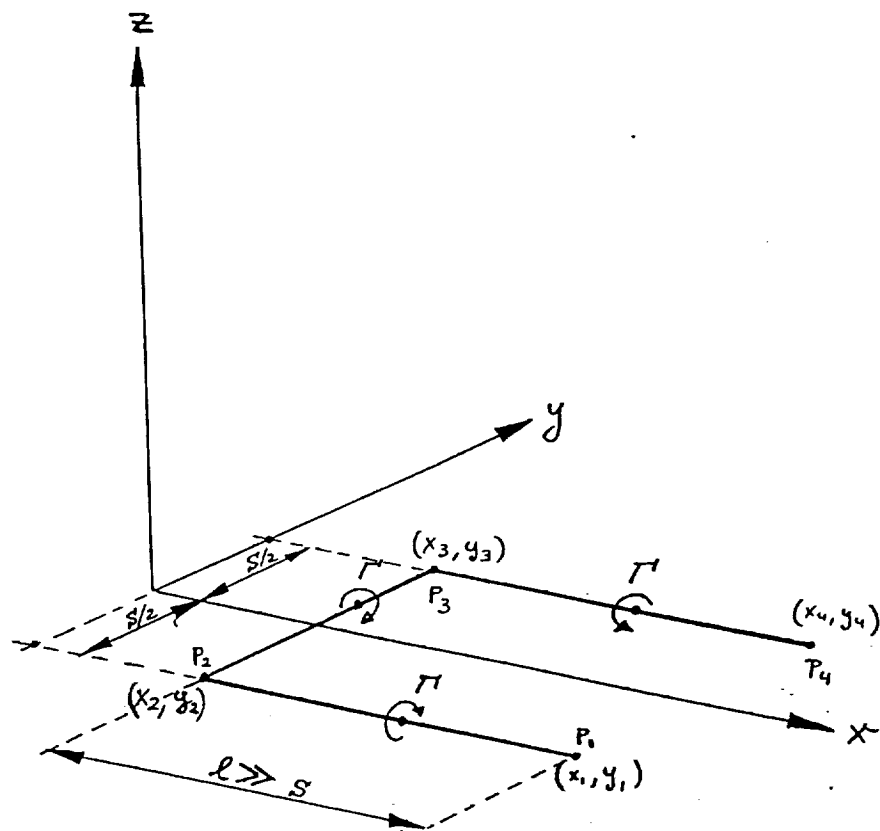
Fig. B-1. Geometry of finite length horseshoe vortex in free-air flow.

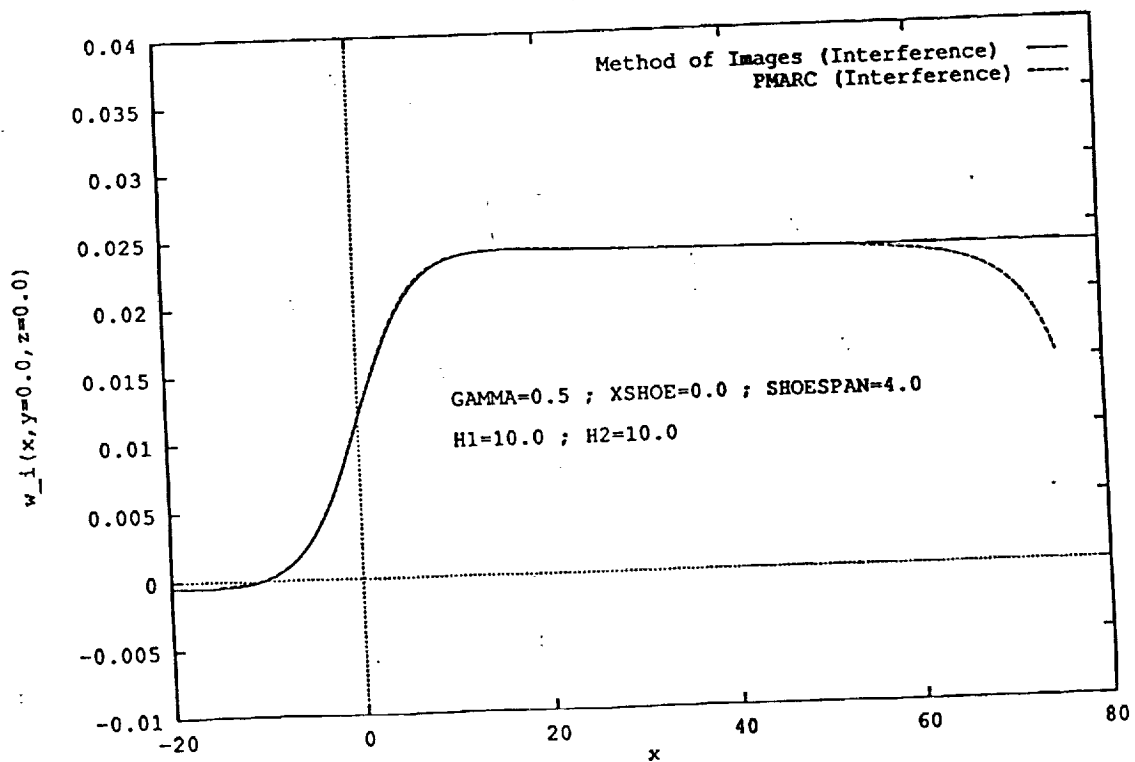**Fig. B-2.** Wall pressure coefficient distribution $c_p(x, y = 0.5, z = 5.0)$ in rectangular wind tunnel.

Fig. B-3. Interference velocity distribution $w_i(x, 0, 0)$ on centerline of rectangular wind tunnel.
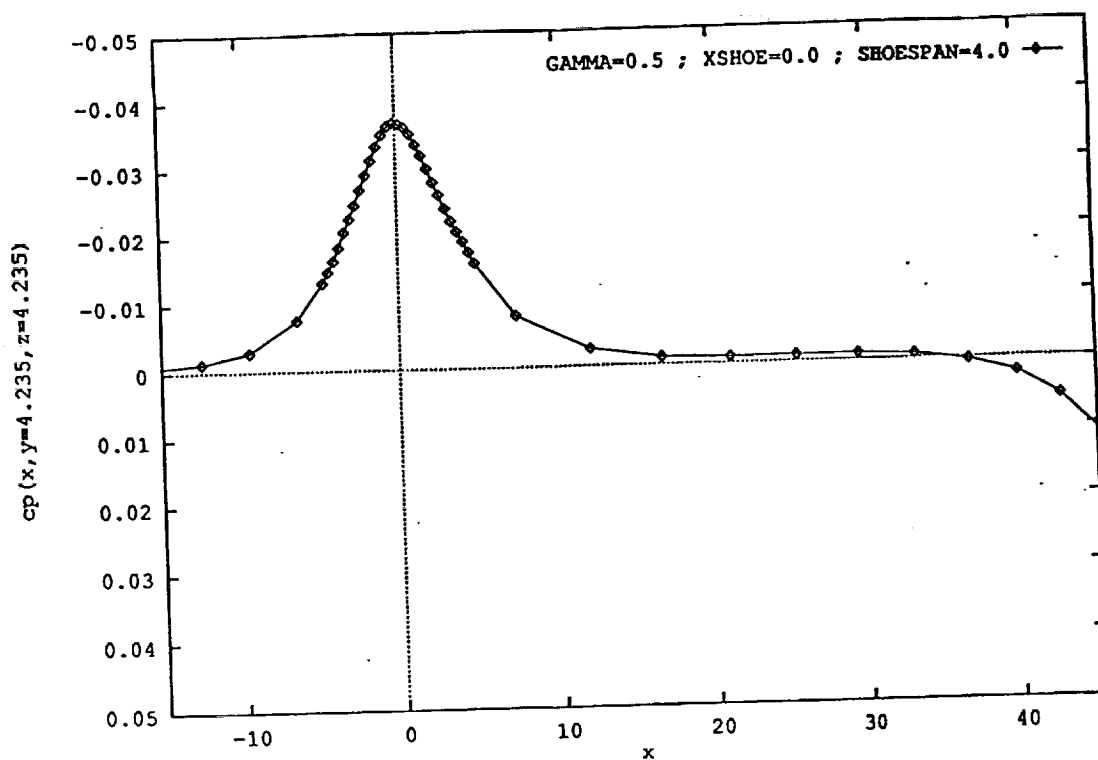
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Fig. B-4. Wall pressure coefficient distribution $c_p(x, y = 4.235, z = 4.235)$ in NACA/ARC 12ft PWT.
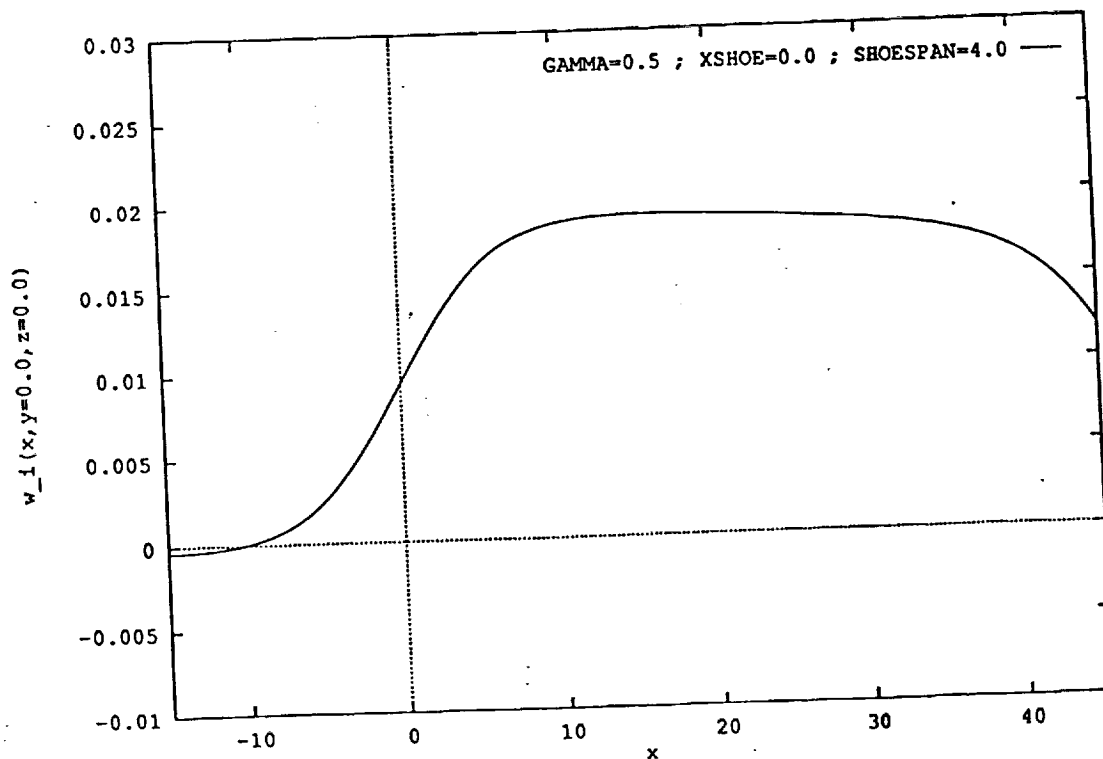
Interference Velocity Component in the z - Direction

Fig. B-5. Interference velocity distribution $w_i(x, 0, 0)$ on centerline of NASA/ARC 12ft PWT.

C. Support Systems Interference

The effect of the model support system in the 12-ft Pressure Tunnel on the tunnel wall pressure signature measurements has been investigated by the PMARC code. Since the Wall Signature method is based upon the wall pressure measurement to estimate the wall interference. The consideration of the effects of the support systems on the wall pressure is critical and essential to accurately assure the wall pressure only induced by wall interference and model effects. Therefore, the study of support systems interference is required to estimate the amount of effects due to the support system.

Selection of PMARC code. The complex geometry of the support systems which consist of a strut and model sting arrangement requires the detail description in order to calculate the flow field. For subsonic flow, the PMARC is an ideal code to investigate this problem. PMARC was designed as an adjustable size panel code which allows the user to adapt the code to the requirements of the computer system being used. This makes it possible to use PMARC virtually any computer system from a PC or Macintosh to an IBM RISC or VAX machine provided the required storage space is available since PMARC creates large temporary files while it runs. Also, since PMARC is a low order panel code, the computation time required by PMARC is much less than that required by higher order panel codes.

Results. Figure C-1 shows the geometry of the test assembly with the inlet and exit planes. The bi-pod support consists of two parallel cylinders placed on the floor of the tunnel. This support is aligned perpendicular to the flow direction and is located at approximately station 20 as specified in the tunnel drawing. Figure C-2 shows the bi-pod support as modeled.

The effect of the strut on the wall pressure can be seen in Fig C-3. The model was centered at station 20 as specified in the drawings for the tunnel. The strut begins at station 30 and extends downstream to station 37.6.The strut blockage causes an increase in the velocity around the strut which results in a corresponding decrease in the pressure coefficient. The strut has little effect on the wall pressure at the model location.

Figure C-4 illustrates the effect of the strut, sting, and model on the wall pressure. The strut does not effect the wall pressure at the model position as seen in Fig C-4. The bi-pod support also has little effect on the wall pressure as can be seen in Fig C-5.
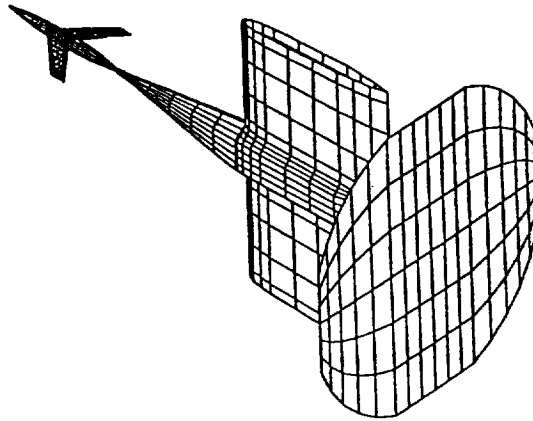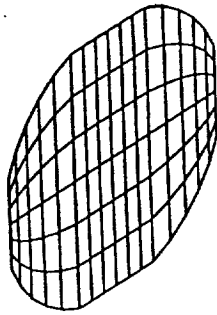
Fig. C-1.   Test Assembly Geometry with Model.
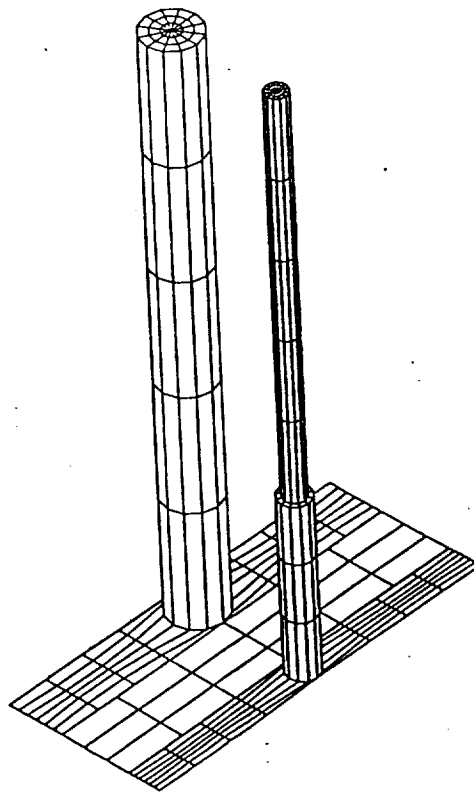

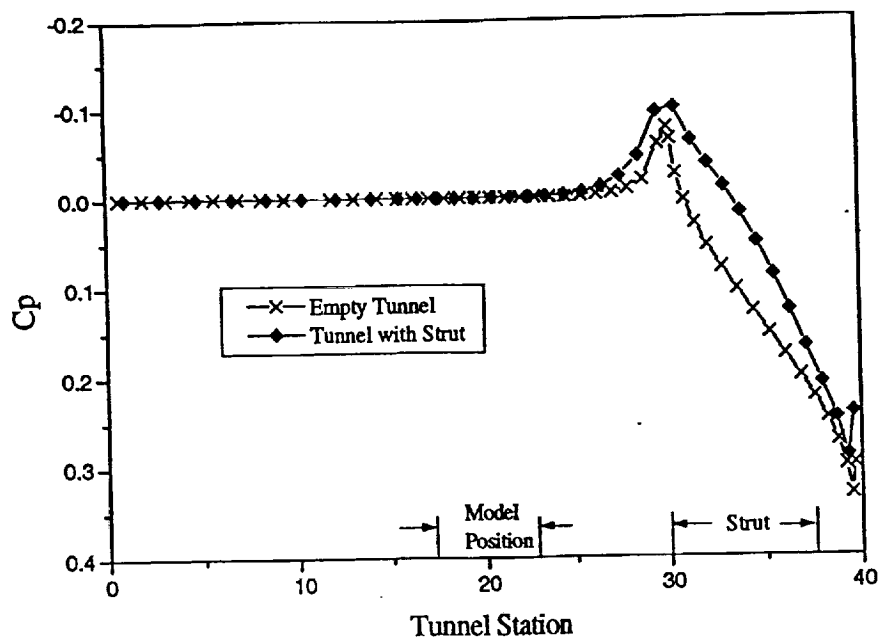**Fig. C-2.**   Bi-pod Support Geometry.

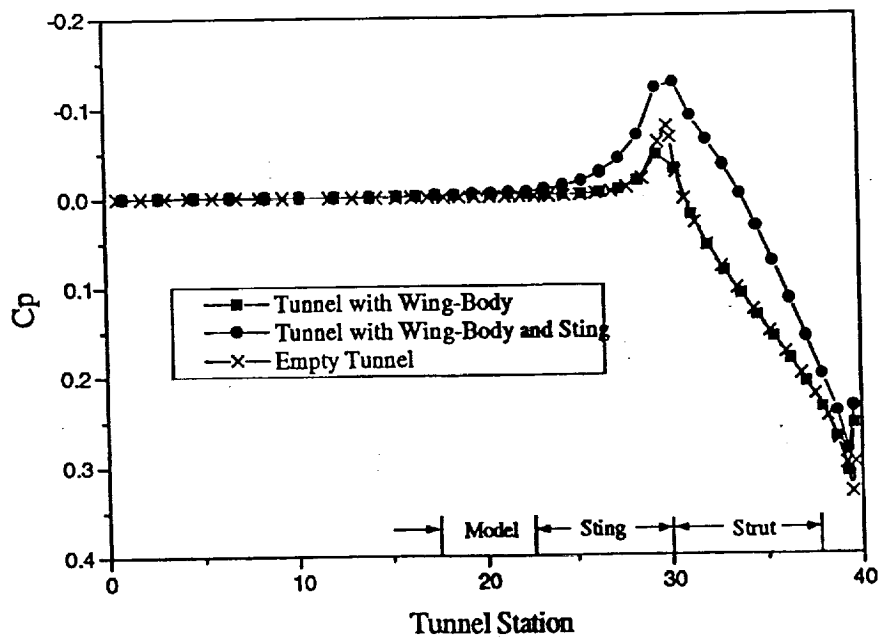**Fig. C-3.** Strut Interference on the Wall Pressure.

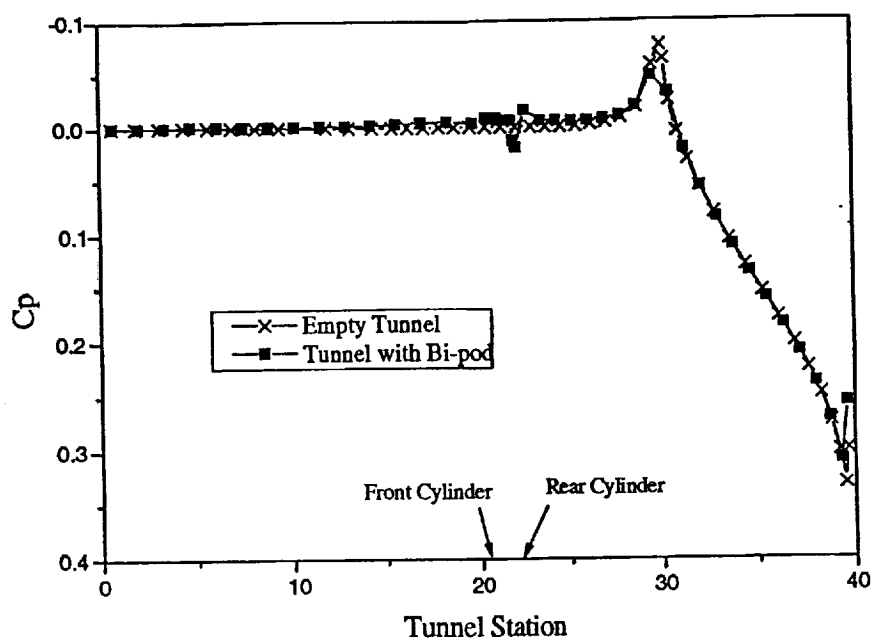**Fig. C-4.** Wing-body Interference on the Wall Pressure.

Fig. C-5. Bi-pod Interference on the Wall Pressure.

Future Plan:

A. The Wall Signature method will be improved to include pre-computed "influence coefficients" of wall interferences for the implementation of on-line interference computation to complete Task 1 of Grant Supplement No.1.

B. The development of the lifting correction of Wall signature method will continue. It will be incorporated into the overall interference correction calculation. The NACA 4412 airfoil is a candidate for the investigation of lifting and blockage interferences together in the next period.

C. The investigation of effects of the model support system in the 12-ft Pressure Tunnel on tunnel wall pressure signature measurements will be combined into the overall interference evaluation to complete Task 2 of Grant Supplement No. 1.

References:

1. Lo, C. F., "A Wall Interference Assessment/Correction system," NASA/Ames Grant NAG 2-733, Semi-annual Report #2, January-June, 1992.

2. Ulbrich, N., Lo, C. F. and Steinle, F. W. "Blockage Correction in Three-Dimensional Wind Tunnel Testing Based on the Wall Signature Method," AIAA 92-3925, presented at the 17th Aerospace Ground Testing Conference, Nashville, TN, July 6-8, 1992.

3. Ulbrich, N., "Wall Interference Correction Based on Interface Measurements in Subsonic Wind Tunnel Testing," Ph. D. dissertation, The University of Tennessee, Knoxville, TN, August 1992.

4. Ashby, D. L., Dudley, M. R., Iguchi, S. K., Browne, L., Katz, J., "Potential Flow Theory and Operation Guide for the Panel Code PMARC," NASA TM 102851, NASA Ames Research Center, Moffett Field, California, January 1991.

5. Hackett, J. E. et al,"A Review of the Wall Pressure Signature and other Tunnel Constraint Correction Methods for High Angle-of-Attacks Tests," AGARD Report No. 692, May 1980.

Appendix I

Basic Elements of the Wall Signature Method

Signature Analysis Procedure

The signature analysis procedure relates variables characterizing the wall signature to an equivalent body representation based on precalculated influence functions. Line sources and sinks are selected by *Hackett et al.* (Ref. 5), to describe the test article and its wake in terms of an equivalent body. A wind tunnel with arbitrary cross–section requires the application of a panel code to determine influence functions and blockage corrections.

A signature analysis procedure is developed to calculate blockage corrections of a wing type body in three–dimensional wind tunnel testing.

The modified signature analysis procedure works as follows: during a wind tunnel experiment of a wing of span s, wall pressure coefficients c_{pw} along a single row of pressure orifices are recorded. The wall pressure coefficient distribution c_{pw} on this row has the characteristic shape depicted in Fig. I-1. The asymptotic value c_{p_0} and the extremum c^*_{pw} of the wall pressure coefficient measurements are shown in Fig. I-1. These values are found by calculating mean values of pressure coefficients.

The total wall signature c_{pw} is split into a symmetric and antisymmetric component :

$$c_{pw} = c_{p_A} + c_{ps} \tag{1}$$

The signature splitting requires an iteration procedure which is terminated as soon as the x–location x_p of the minimum of the symmetric signature c_{ps} agrees with the location of the inflection point x_p of the antisymmetric signature c_{p_A} .

The equivalent representation of the test article in terms of a line source and a line sink apart a finite distance is derived from the symmetric signature; the representation of the wake in terms of a line source and a line sink is derived from the antisymmetric signature; the equivalent body is found by superimposing the representation of the test article and wake (a total of two line sources and two line sinks). This equivalent body is used to compute blockage corrections.

The test article is described by a line source and a line sink of equal span s, equal strength $\pm Q_s$ and line source / sink distance d . Similarly, the idealized trailing edge wake is represented by a line source and line sink of equal span s and equal strength $\pm Q_w$. In this case the distance between the line source and line sink is selected to be a large value, i.e. $d_w \gg s$. The idealized test article and wake representation are shown in Fig. I-2.

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The equivalent representation of the test article and its wake is found, when s, $\pm Q_s$, d, $\pm Q_w$ and x_p are known. The equivalent representation is obtained as follows: (1) get the asymptotic value of the wall pressure coefficient distribution c_{p_0} from the wall pressure measurement; (2) consider the test article span s as the span of the equivalent body; (3) use c_{p_0} and s in combination with the precalculated influence function $f_1(s)$ to obtain Q_w ; influence function $f_1(s)$ can be considered as a normalized asymptotic pressure coefficient (see Fig. I-3); (4) use the precalculated influence function $f_2(s)$ to get the slope of the antisymmetric signature dc_{p_A}/dx_p at the inflection point; influence function $f_2(s)$ can be considered as the normalized inflection point slope (see Fig. I-4); (5) guess the value of x_p; (6) subtract *Hackett's* (Ref. 5) approximation of the antisymmetric signature c_{p_A} from the wall pressure signature c_{p_W} to get the symmetric signature c_{p_S} ; (7) repeat steps (5) and (6) in an iteration procedure until the location x_p of the minimum $c_{p_{min}}$ of the symmetric signature c_{p_S} agrees with the inflection point location x_p of the approximated antisymmetric signature c_{p_A} .

The description of the idealized trailing edge wake in terms of s, $\pm Q_w$ and x_p is now determined. The calculation of the idealized test article representation requires further steps.

Two parameter are derived from the symmetric signature, i.e., the width at half height Δx of the symmetric signature and the minimum of the symmetric signature $c_{p_{min}}$ (see Fig. I-1). These parameter are related to the distance d and singularity strength Q_s . Functional relationships between d, Q_s, Δx and $c_{p_{min}}$ are given by precalculated influence function $H_1(s,d)$ and $H_2(s,d)$. Influence function $H_1(s,d)$ can be considered as the width at half height Δx of the symmetric signature c_{p_S} (see Fig. I-5); influence function $H_2(s,d)$ can be considered as the normalized pressure coefficient minimum of the symmetric signature (see Fig. I-6).

The value of d is found as follows : (1) apply a least squares fit based on a Gaussian (for more detail see Ref. 2 and 3) to the symmetric signature c_{p_S} and calculate the width of the signature at half height Δx and the minimum $c_{p_{min}}$; (2) use influence functions $H_1(s,d)$ and $H_2(s,d)$ to obtain d and Q_s for the given values of Δx and $c_{p_{min}}$.

The values of d and Q_s in combination with the known value of x_p and s define the representation of the test article. The values of x_{source} and x_{sink} are derived from x_p and d (see Fig. I-2).

The superimposed velocity fields of the representation of the wake in terms of x_p, $\pm Q_w$,s and of the equivalent representation of the test article in terms of x_{source}, x_{sink}, $\pm Q_s$ will reproduce the wall signature.

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Calculation of Blockage Corrections

The equivalent representation of the test article and its trailing edge wake in terms of two line sources and two line sinks is known after the successful completion of the signature analysis procedure. The test article is described by s, $\pm Q_s$, x_{source} and x_{sink} ; the trailing edge wake is described in terms of s, $\pm Q_w$ and x_p . The modified version of the panel code PMARC (Ref. 4) which is described in detail in Appendix II is used to obtain the blockage correction based on the known line source / sink in the form of a pressure coefficient correction $c_{p_i}(x, y, z)$.
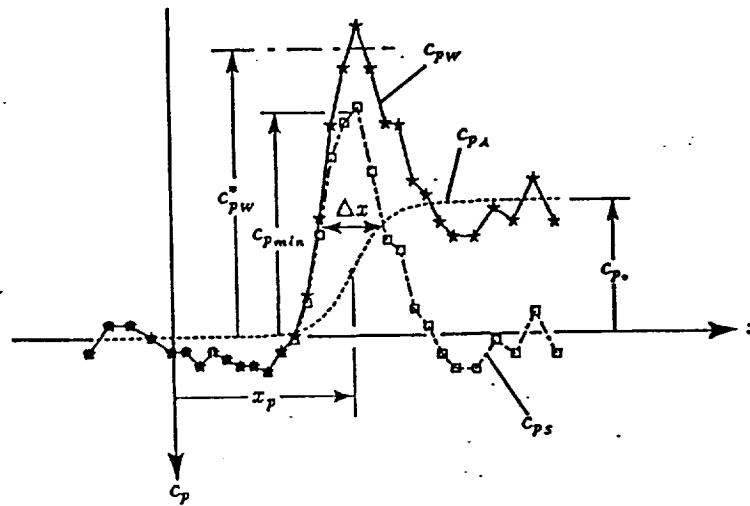
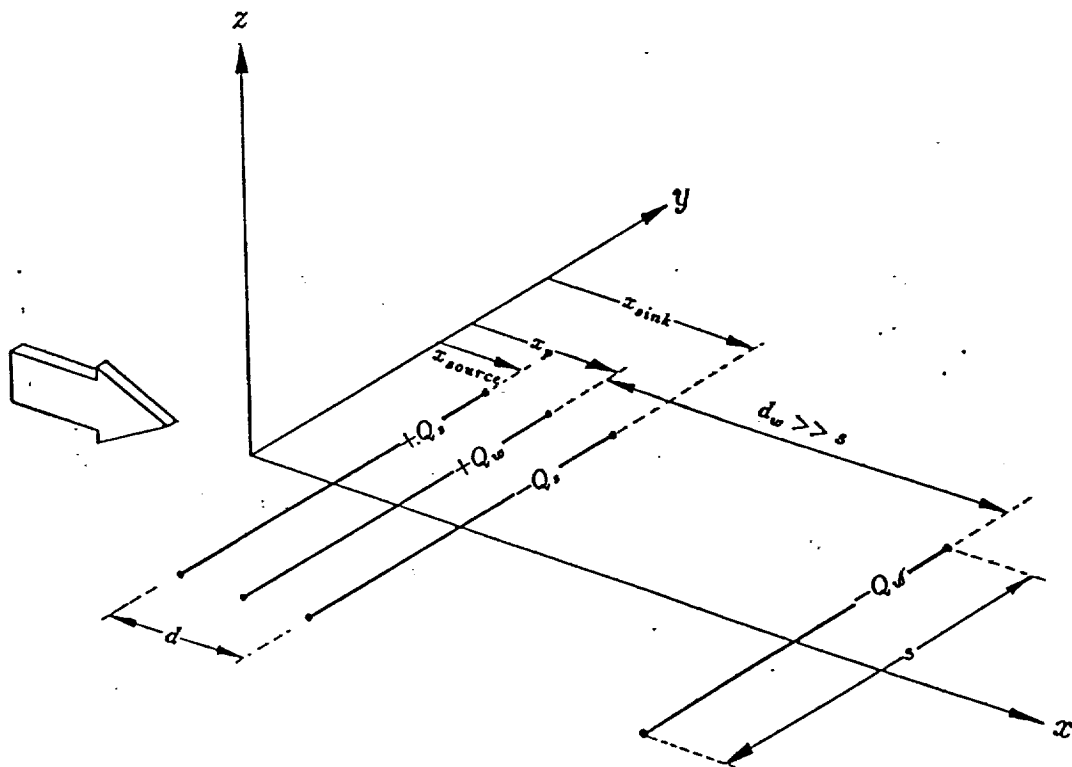**Fig. I-1.** Wall pressure signature c_{pw} represented as sum of symmetric part c_{ps} and antisymmetric part c_{p_A} .

Fig. I-2. Representation of test article and wake in terms of a line source and line sink.
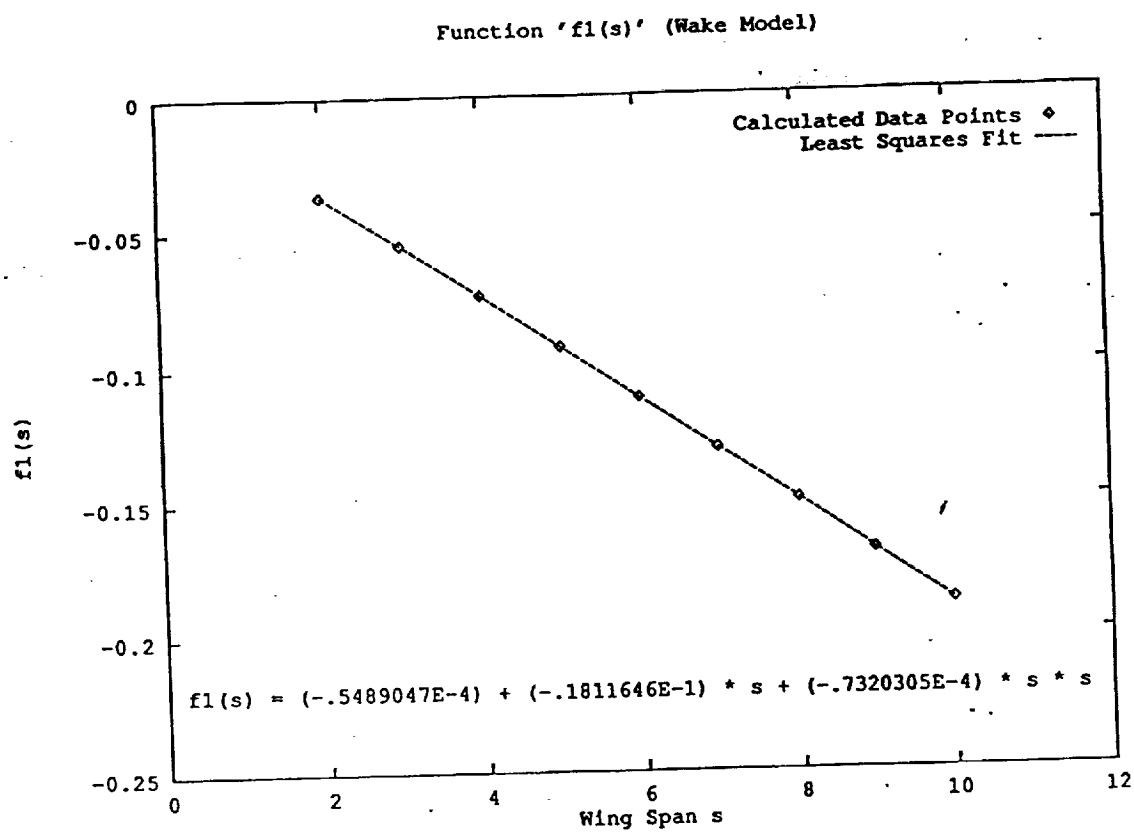
Function 'f1(s)' (Wake Model)

f1(s) = (−.5489047E−4) + (−.1811646E−1) * s + (−.7320305E−4) * s * s

Fig. I-3.   Influence function $f_1(s)$.

Function 'f2(s)' (Wake Model)

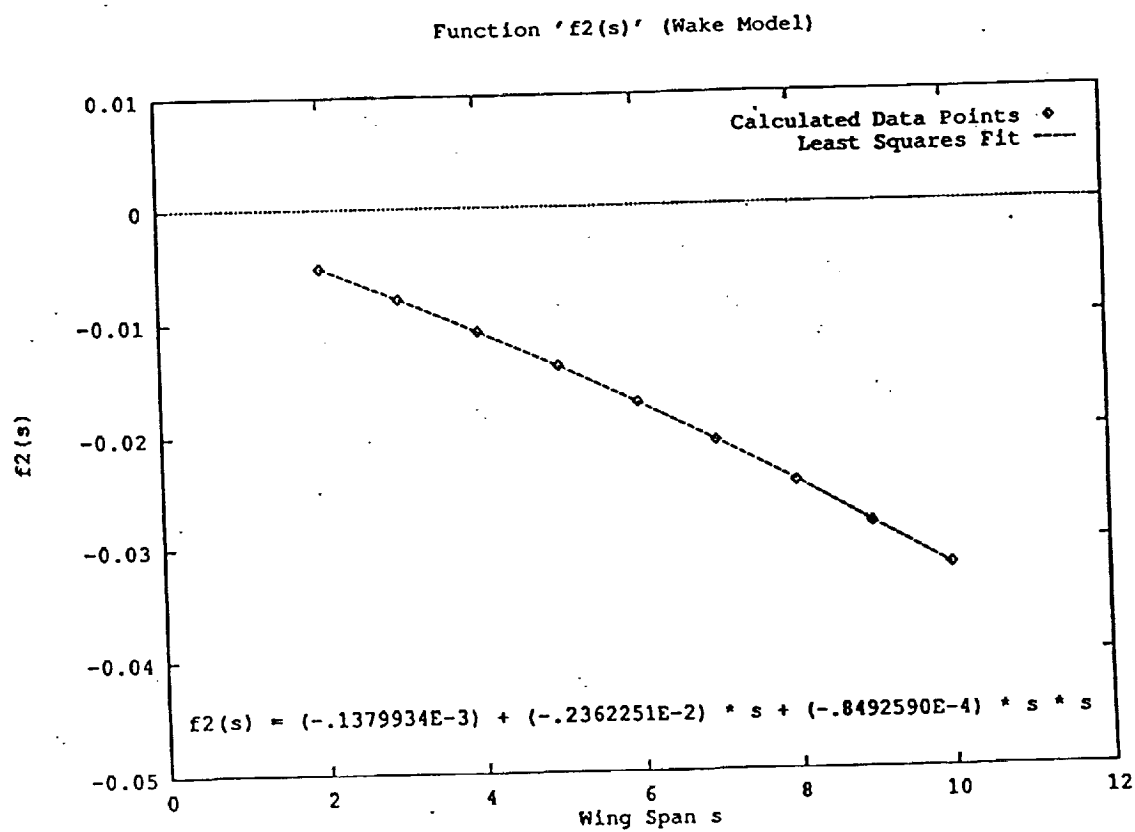f2(s) = (−.1379934E−3) + (−.2362251E−2) * s + (−.8492590E−4) * s * s

Fig. I-4.   Influence function $f_2(s)$.
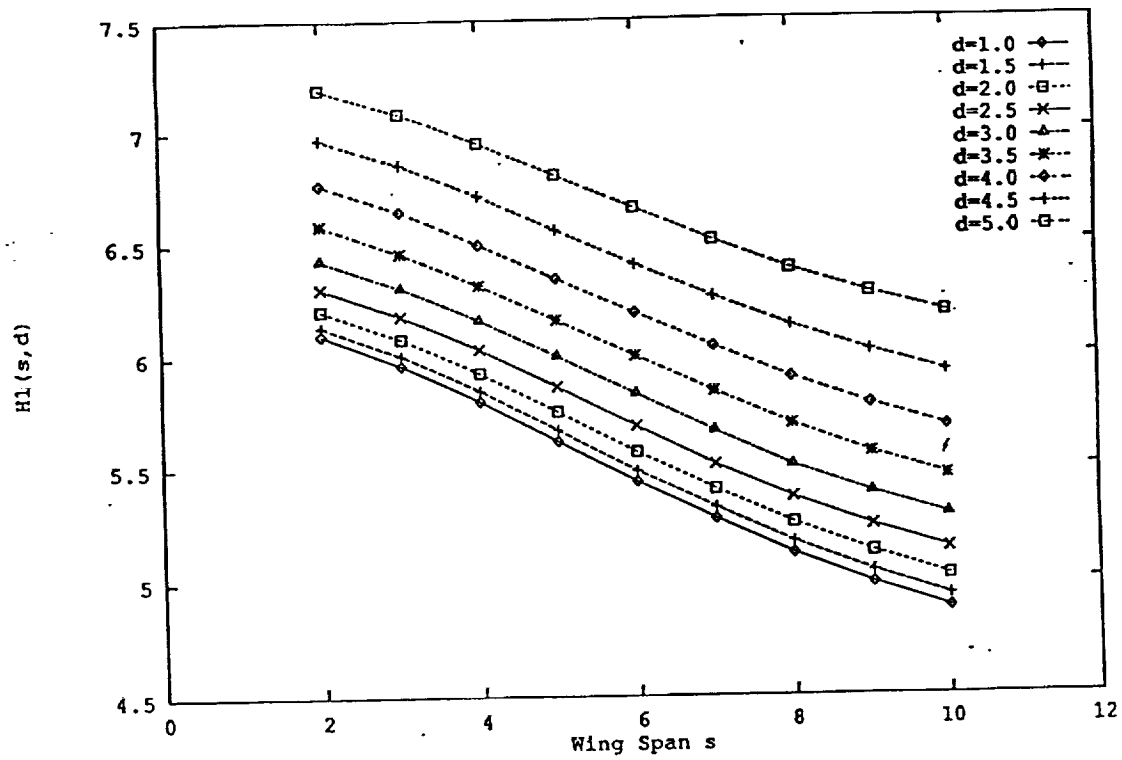
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Function 'H1(s,d)' (Solid Body Model)

Fig. I-5. Influence function $H_1(s, d)$.
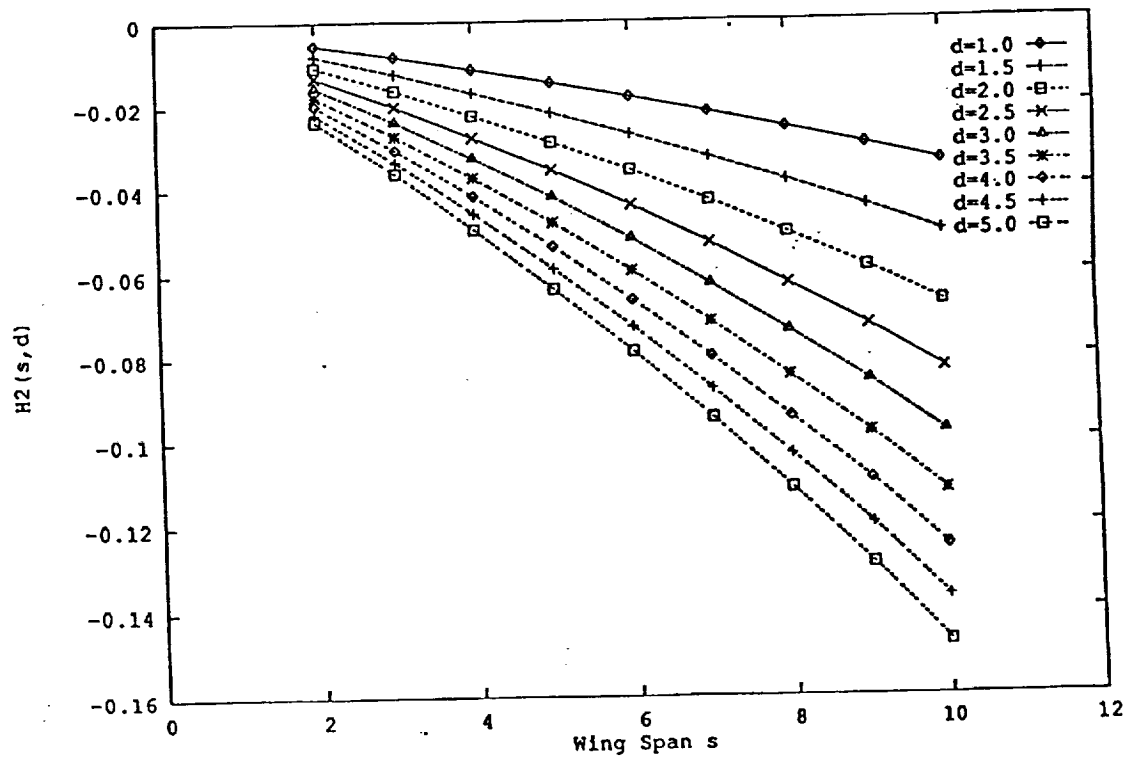
Function 'H2(s,d)' (Solid Body Model)

Fig. I-6. Influence function $H_2(s, d)$.

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Appendix II

Interference Calculation based on a Combination of Model Singularities with a Panel Code

Panel code PMARC solves for a velocity potential of a given boundary value problem. This boundary value problem is defined by specifying the surface geometry of test article and wind tunnel wall. Normal velocities are given on panel surfaces. The perturbation potential ϕ_t of the tunnel flow field can be expressed as follows:

$$\phi_t = \phi_m + \phi_i \tag{2}$$

where ϕ_m is the free-air model perturbation potential and ϕ_i is the interference perturbation potential. The Laplace equation has to be fulfilled in the wind tunnel flow field and so we get:

$$\nabla^2 \phi_t = \nabla^2 \phi_m + \nabla^2 \phi_i = 0 \tag{3a}$$

with the boundary conditions on the solid wind tunnel wall:

$$\frac{\partial \phi_t}{\partial n} = \frac{\partial \phi_m}{\partial n} + \frac{\partial \phi_i}{\partial n} = 0 \tag{3b}$$

The model perturbation potential ϕ_m fulfills the Laplace Equation, i.e., $\nabla^2 \phi_m = 0$, and Eq. (3a) can therefore be written as:

$$\nabla^2 \phi_i = 0 \tag{3c}$$

Boundary conditions of the interference flow field can be obtained by rearranging Eq. (3b). We get:

$$\frac{\partial \phi_i}{\partial n} = -\frac{\partial \phi_m}{\partial n} \tag{3d}$$

Thus, the boundary value problem of the interference perturbation potential, ϕ_i, can be determined, if the normal velocities on the wind tunnel wall are specified to be the negative of the normal velocity component induced by the model flow on the same panel location.

Panel code PMARC has a user–option to specify normal velocities on all wall surface and inlet panels. The boundary condition of the interference flow field is specified by adding the negative of the normal velocity component of the free–air model flow field on the same panel centroid location to the normal velocity component. The free-air model flow field is given as the analytic solution of the flow field of model singularities in free-air flow.

The modified PMARC solves for unknown doublet strengths of the interference flow field as the boundary conditions of the interference flow field are specified; the wind

tunnel flow field is obtained by adding the known free-air velocity vector of model singularities to the interference solution.

The modified PMARC code is evaluated by comparing the calculated flow field of a horseshoe vortex in a rectangular wind tunnel with the corresponding solution obtained from the Method of Images as given in Section B.